

**The influence of typeface fluency on simple sentence encoding as measured through
spectral power analysis.**

Katherine Hope Kenyon

*This thesis is submitted in partial fulfilment of the Honours degree of Bachelor of
Psychological Science (Honours).*

School of Psychology
Faculty of Health and Medical Sciences
University of Adelaide

October 2019

Word count: 9,120

Table of Contents

List of figures.....	4
Abstract.....	5
Declaration.....	6
Acknowledgements.....	7
The influence of typeface fluency on simple sentence encoding as measured through spectral power analysis.	8
Language Encoding	8
Areas of the Brain Involved.....	10
EEG Measures and Spectral Power	11
Alpha and Alpha Power.	12
Theta and Theta Power.....	13
Using Spectral Power to Measure the Strength of Language Encoding.....	14
Typeface Fluency and Encoding.....	16
The Present Study	19
Method	21
Participants.....	21
Materials	22
Alien Species task.....	22
One-back Task.....	22
Raven’s Progressive Matrices (RPM).....	23

Group Embedded Figure Test (GEFT).....	23
Apparatus	23
Procedure	24
1. Baseline.....	24
2. Learning Phase.....	24
3. Distractor Phase.	24
4. Recall Phase.	24
Data Analysis	25
Statistical Analysis	26
Results.....	28
Behavioural Analysis	28
Spectral Analysis.....	28
Discussion.....	33
References.....	42
Appendix A: Alien Task.....	58
Appendix B: Tests of fixed effects.....	Error! Bookmark not defined.

List of figures

Figure	Page
1. Compumedics Neuroscan 64-channel Quik-Cap electrodes used for regional and hemispheric analysis.....	23
2. Average alpha activity during the encoding phase for fluent (top) and disfluent (bottom) conditions.....	25
3. Average theta activity during the encoding phase for fluent (top) and disfluent (bottom) conditions.....	26
4. Boxplot of alpha power relative to baseline eyes open across fluent and disfluent conditions.....	27
5. Boxplot of theta power relative to baseline eyes open across fluent and disfluent conditions.....	27
6. Differences in alpha power between brain regions for fluent and disfluent conditions.....	28

Abstract

Previous research has shown that typeface fluency has an impact on the encoding and processing of written texts. Specifically, less fluent letters and words appear to be processed more deeply and remembered more accurately. To date, there is limited research regarding the mechanisms by which typeface fluency impacts on the encoding of full sentences. Therefore, this study aimed to expand on this research by focusing on the way it can be applied to the encoding of full sentences. Participants were asked to memorise simple sentences presented in either a fluent or disfluent typeface. Electroencephalography was used to record the changes in spectral power during the learning phase in order to determine the level of encoding success. Following a period of distraction, an audio-presented recall task was used to assess recall accuracy. Fluency was found to be associated with changes in alpha power at learning. Further, alpha power significantly differed between the parietal and occipital regions of the brain but did not show any reaction with fluency. Due to performance ceiling effects, these findings could not be associated with memory outcomes. This research is especially relevant to education, as much of the information presented in schooling is digitally presented text.

Keywords: electroencephalography, spectral power, typeface fluency, language encoding, typography

Declaration

This thesis contains no material which has been accepted for the award of any other degree or diploma in any University, and, to the best of my knowledge, this thesis contains no material previously published except where due reference is made. I give permission for the digital version of this thesis to be made available on the web, via the University of Adelaide's digital thesis repository, the Library Search and through web search engines, unless permission has been granted by the School to restrict access for a period of time.

Signed:

Acknowledgements

I would firstly like to thank my supervisor Dr. Mark Kohler for his support, encouragement and guidance, and the rest of our little typeface study research team, Toby Jones and Dr. Scott Coussens, for all of your help throughout the year. I would also like to say a big thank you to my support networks both in Melbourne and Adelaide, I could not have gotten through this year without you.

The influence of typeface fluency on simple sentence encoding as measured through spectral power analysis.

Our ability to communicate effectively through language is crucial for the spread of information and the advancement of society. From around 3500BCE, humans have used script to communicate visually, which developed from earlier uses of tokens and other imagery (Schmandt-Besserat, 2014). Since then, written language has become a key way for information to be presented and shared. The linguistic study of written language became a more prominent area of investigation in the 1970s (Schmandt-Besserat & Erard, 2008). Psychologists and typographers have studied the way humans process written information. While understanding language and deriving meaning from it appears to be a simple task, being cognizant of the underlying mechanisms of language processing and comprehension is a far more difficult task (Bastiaansen & Hagoort, 2006). Researchers have more recently begun to discover the impact of the way the text is visually presented on how written information is processed in the brain, and how well that information is retained. This is important knowledge for a range of contexts, such as education and marketing, where the retaining of presented information is crucial for success. While there is evidence for the connection between the visual features of written language and information processing and recall, there is little known regarding the impact of such visual features on the brain activity that underlies the encoding of such information. Moreover, there is even less on the impact of visual features on encoding written sentences of information. This study will address this gap in the present literature.

Language Encoding

Encoding is the process by which presented information is registered and processed in the brain (Baddeley, 1976). The success of encoding influences one's ability to store and retrieve this information. Effective communication requires both a ready store of contextually

appropriate responses, as well as the ability to attend to, process and interpret received information. The ability to encode language is therefore especially important. Understanding the mechanisms around language encoding and processing is both fascinating and essential, as it will allow us to explore how the mechanisms of language processing in the brain work, how they can fail or work differently in people with language disorders, and how to maximize our recall ability based on manipulation of factors that affect our language encoding abilities. Encoding of individual letters has been found to be essential for the processing of language (Paap & Ogden, 1981). Keage, Coussens, Kohler, Thiessen, and Churches (2014) found that the visual features of individual written letters affect their processing. Their results suggest that it is more difficult to initially abstract letter meaning when a letter is less legible. In fact, several studies have shown that the visual features of single letters influence their encoding success (Thiessen, Kohler, Churches, Coussens, & Keage, 2015; Wamain, Tallet, Zanone, & Longcamp, 2012). Such features include a relationship to movement-based information such as with handwriting and script (or motor familiarity) (Wamain et al., 2012), letter width, and the vertical and horizontal strokes of each letter (Thiessen et al., 2015). Moreover, the encoding of separate words has been widely studied. Physical variables such as word-background colour contrast, case and style are thought to have a moderate effect on word encoding (Barton, Fox, Sekunova, & Iaria, 2010; Wickens, 1973). Research on word processing has primarily focused on both wider neuronal activity and specific brain regions involved in word encoding (Clark & Wagner, 2003; Mei et al., 2010; Weiss & Rappelsberger, 2000), and have found increased neural activity parietal and frontal cortices during word memorization tasks, as well as changes in coherence depending on recall accuracy. Mei et al. (2010) found that the left fusiform cortex, or the visual word form area, plays a role in the successful the processing and learning of visual information. This area has also been found to be more active in stronger readers and is said to

specifically support the encoding of words. Allen, Madden, and Slane (1995) stated that visual word encoding is the first step in the process of reading. However, natural language is not presented as single letters or words very often. Instead, we tend to communicate information through the use of full sentences (Hasson, Nusbaum, & Small, 2007). Therefore, the most accurate and generalisable way to study encoding of language is through looking at whole sentences.

Areas of the Brain Involved. Activity in both hemispheres of the brain have been linked to different aspects of written language processing (Barton et al., 2010). Reading is largely based in the left inferior temporo-occipital area (Baldo et al., 2018). Specifically, sentence-level reading has been associated with activation of the left anterior-mid of the medial and superior temporal gyri. Left posterior ventral temporal zones have in fact been labelled the “visual word form area” (McCandliss, Cohen, & Dehaene, 2003). A computerized tomography study found that the left perisylvian cortex plays a role in verbal short term memory (STM) (Koenigs et al., 2011). Computerised Tomography (CT) has shown sentence-reading comprehension to be positively correlated using to activity in the left parahippocampus and right calcarine fissure, and oral word reading was positively correlated with activity in the left superior temporal gyrus, left inferior temporal gyrus, left supramarginal gyrus and right superior temporal gyrus (Xia et al., 2017). Lesions in the left fusiform area can impair the reading of text, and lesions in the right have been found to impair handwriting recognition specifically (Barton et al., 2010). These findings suggest strong hemispheric differences in language encoding, and Spironelli and Angrilli (2010) suggest that functional lateralisation is in fact necessary for humans to fully realise their linguistic potential.

EEG Measures and Spectral Power

While imaging has helped identify the major regions and structure important for language processing, such techniques do not capture the sequences of processes in real time well. Language encoding processes can be measured using several different techniques with high temporal resolution. A popular method for this is using an electroencephalogram (EEG) to measure the electrical signals in the brain. The precise temporal resolution of EEG enables the capture of neuronal activity evoked by stimuli, including the encoding process (Teplan, 2002). One way to use this technology is to analyse the event related potential (ERP), or stimulus-locked neural activity during a language task. ERP analysis is a popular way to study language processing, and such research makes up a large proportion of the EEG-based language studies (Weiss & Mueller, 2003). ERPs reflect global electrical activity in the brain (Kaan, 2007), and different components have been linked to different linguistic processes. For example, the N400 is a negative waveform that occurs 400ms after stimulus onset, and is particularly linked to sentence-final words (Friederici, 2004). This is often larger over the right hemisphere with visually presented words. Additionally, the P600 is a positive waveform that occurs 600ms after stimulus presentation, and is associated with violations or difficulties with sentence structure (Friederici, 2004). ERP analysis is beneficial for language processing research as its high temporal resolution matches the rate of language comprehension, and thus allows researchers to track processing throughout a language task (Kaan, 2007). However, ERPs only consist of phase-locked activity. Interactive brain systems show changes throughout the duration of processing rather than through specific waveform amplitude changes, and therefore ERPs only give a rough estimate of the whole electrical response (Weiss & Mueller, 2003). Another way to analyse language processing using EEG is to analyse specific frequency bands of neural activity. These frequency bands are thought to

have a crucial role in linking areas of the brain that are a part of the functional network involved in language processing (Bastiaansen & Hagoort, 2006). Each frequency band can be isolated using EEG and can be analysed with respect to stimulus presentation. Spectral analysis is able to monitor global synchronisations and desynchronisations between frequency bands and electrodes (Weiss & Mueller, 2003). It is therefore a useful way to measure electrical activity across the cortex during a language processing task, and successfully compliments ERP findings. Grabner, Brunner, Leeb, Neuper, and Pfurtscheller (2007) state that language processing is primarily reflected in the alpha and theta frequency bands.

Alpha and Alpha Power. Alpha waves are electrical brainwaves with a frequency between 8-13Hz. There has been extensive research into this frequency band and into the sorts of activities it is associated with. Geske and Bellur (2008) found that the ventral stream in the brain showed alpha changes associated with processing of line, shape and form information. Additionally, alpha in the dorsal stream was associated with spatial processing and focus of attention (Geske & Bellur, 2008). This study showed that alpha waves are found primarily in the occipital and parietal lobes of the brain, and that they are inversely related to task difficulty. It has also been associated with preparatory visual attention (Bacigalupo & Luck, 2019), cognitive performance and processing speed (Klimesch, 1999), and is thought to reflect inhibitory top-down control of task processing and executive functioning (Fell et al., 2011). While some studies do suggest otherwise, (Poliakov, Stokes, Woolrich, Mantini, & Astle, 2014), most research shows an inverse correlation between alpha activity during encoding and cognitive performance. Cognitive performance has specifically been associated with a decrease in alpha power (Klimesch, Sauseng, & Hanslmayr, 2007), and when such changes occur in response to a particular stimulus or event, it is called event related desynchronisation (ERD, for a decrease in activity) in the alpha band. Conversely, event

related synchronization (ERS) in the alpha range refers to an increase in activity (Pfurtscheller & Da Silva, 1999). Specifically, ERD is the percentage of change in frequency band power within a particular time interval with respect to a reference (Klimesch, Russegger, Doppelmayr, & Pachinger, 1998). Klimesch (1999) specifically found an increase in ERD in the left hemisphere at the time of semantic judgement, which is suggested to be due to an increase in attention required. ERD is also associated with an increase in attention (Klimesch, 1999; Mathewson et al., 2011; Pfurtscheller & Da Silva, 1999; Pfurtscheller, Neuper, & Mohl, 1994). More precisely, a decrease of activity in response to attention engagement is found predominantly in the lower alpha band range (8-10Hz). The upper alpha band (11-13Hz) on the other hand, has been associated with the processing of sensory-semantic information (Klimesch, 1999; Pfurtscheller & Da Silva, 1999). A decrease in left hemisphere alpha activity has been linked to the performance of language tasks (Grabow, Aronson, Greene, & Oforfd, 1979). Specifically, alpha ERD occurs following stimulus onset in reading and semantic tasks. This desynchronisation in the alpha band appears to be maximal after a full sentence has been presented, therefore reflecting sentence comprehension (Röhm, Klimesch, Haider, & Doppelmayr, 2001).

Theta and Theta Power. Theta frequencies range between 4-8Hz and are also important for memory encoding (Werkle-Bergner, Müller, Li, & Lindenberger, 2006). Oscillations within this frequency band have been specifically associated with remembering words, and increased theta power during encoding has been related to memory processing (White et al., 2013) and increased recall success (Hanslmayr, Spitzer, & Bäuml, 2008). Werkle-Bergner and colleagues (2006) suggest that this is due to a link between theta activity and long-term potentiation - the mechanism responsible for creating memory traces. Additionally, theta ERS in the frontal area is believed to reflect the activation of neural networks responsible for the allocation of attention (Missonnier et al., 2006), thereby aiding

the encoding of relevant information. A theta power increase can be seen approximately 100-600ms following stimulus onset, and occurs for both open class (nouns, verbs and adjectives) and closed class (articles, prepositions and determiners) words (Bastiaansen & Hagoort, 2006). Theta band activity has been specifically linked to the lexical-semantic retrieval process, due to differences in power between open and closed class words (Grabner et al., 2007). It is also expected to indicate an interaction between the other important memory structures, such as the hippocampus and the cortex (Bastiaansen & Hagoort, 2003). In their 2003 paper, Bastiaansen and Hagoort state that hippocampo-cortical circuits are thought to be the origin of much theta band activity, and thus any scalp-recorded activity through EEG would be reflective of the activity in these circuits. As the hippocampus plays a crucial role in memory formation (Izquierdo & Medina, 1997), this further highlights the connection between theta activity and memory processes.

Using Spectral Power to Measure the Strength of Language Encoding

There has been ample research conducted using alpha power to measure sentence encoding, both in a linguistic sense and in a visual sense for written language. An early study found that words associated with an immediate reduction in alpha activity are recalled better than words not associated with alpha reduction (Warren, Peltz, & Haueter, 1976). Alpha oscillations have been linked to both language and working memory (WM), both of which play a crucial role in sentence processing (Meyer, Obleser, & Friederici, 2013). Further, ERD has been associated with the successful encoding of sentences into WM (Vassileiou, Meyer, Beese, & Friederici, 2018). These findings focus on syntactic, or sentence structure features, rather than lexical-semantic, or word-based features, and suggest that a decrease in alpha power is indicative of successful sentence encoding. Due to the link between ERD and sentence structure, the decrease in alpha power found when encoding words from lists into WM (Fellner, Bäuml, & Hanslmayr, 2013) is weaker than when encoding words from a full

sentence into WM (Lam, Schoffelen, Uddén, Hultén, & Hagoort, 2016). The basis for this effect was thought to be the greater demand of extracting words from a sentence as opposed to words presented separately, as greater neural activation is required to process whole sentences, compared to single words. ERD has been found both before and during the presentation of visual stimuli, suggesting that ERD is associated with both visual and cognitive aspects of language processing (Pfurtscheller et al., 1994). A decrease in alpha power when reading is thought to be due to the increased executive function required (Scharinger, Kammerer, & Gerjets, 2015), and this suggests active visual processing (Wianda & Ross, 2019) and semantic processing (Fellner et al., 2013). Combined, these findings suggest that a decrease in alpha power underlies the successful encoding of language (Klimesch et al., 1996; Vassileiou et al., 2018).

Synchronisation of theta band activity has been related to the retrieval of lexical information from long term memory stores (Grabner et al., 2007). This power increase is associated with the successful encoding of information (Lin et al., 2017). A global increase of theta power has also been associated with the encoding of language, both at the word level and sentence level (Bastiaansen, Van Berkum, & Hagoort, 2002). Studies completed by Klimesch and colleagues provide evidence for theta ERS during both the encoding and retrieval of linguistic information. This synchronisation is greater for participants who score highly on recall tasks than those who perform poorly (Klimesch & Doppelmayr, 1996; Klimesch, Doppelmayr, Schimke, & B., 1997). Moreover, theta power increases are observed during the encoding of visual lexical information specifically (Bastiaansen, Oostenveld, Jensen, & Hagoort, 2008). Although some research suggests that there is no relationship between language processing and theta activity (Röhm et al., 2001), it is overwhelmed by evidence in support of such a connection (Bastiaansen et al., 2008; Klimesch, 1999). The hippocampal network, including its links to the cortex, is thought to support language

processing, which is evidenced by theta power increases (Covington & Duff, 2016; Piai et al., 2016). Stronger theta power is found during sentence encoding in comparison to encoding words from a list (Lam et al., 2016).

In addition to analysing alpha or theta alone, comparing levels of alpha and theta power during encoding further supports the link between spectral power changes and encoding (Fell et al., 2011; Klimesch et al., 1997). ERS in the theta band combined with ERD in the alpha band has been associated with intentional encoding of information (Mölle, Marshall, Fehm, & Born, 2002) and memory performance (Klimesch, 1999). Further, Klimesch, Fellinger, and Freunberger (2011) found that theta ERS and alpha ERD develop in the same time window following stimulus presentation. Finally, a theta power increase and alpha power decrease is found following the presentation of words in a sentence (Bastiaansen, van Berkum, & Hagoort, 2002). This implies a relationship between alpha ERD and theta ERS during encoding of new information. One explanation for how this interaction of alpha and theta jointly aid language encoding is that while alpha activity is associated with neural activity inhibition (Jensen & Mazaheri, 2010), theta is associated with an increase in neural activity, especially during learning and memory-based tasks (Kahana, 2006). Therefore, a decrease in alpha power and simultaneous increase in theta power at stimulus onset is associated with an increase in neural activity throughout the encoding process.

Typeface Fluency and Encoding

A range of features can influence the encoding of written information. Typeface refers to the collection of these features that vary to create a particular font. As such, a font is a particular presentation of typeface features that may differ in size, weight or boldness, slope or italicization, and width (Carter, Meggs, & Day, 2011). The fluency of a typeface refers to how legible it is, or how similar the individual letters are (Keage et al., 2014; Thiessen et al., 2015). It is important to note that fluency is not necessarily about the readability of the

typeface, although they are related constructs. Typeface fluency is instead determined by the ease of distinguishing each letter, rather than readability specifically (Oppenheimer & Frank, 2008). Features that influence typeface fluency include italicization, greyscale percentage and whether it is serif (has small lines at the end of larger strokes) or sans-serif (does not have any such embellishment) (Beier, 2013; Lonsdale, 2014). For example, a typeface with no italicization, presented in black, and without serifs, would be considered more fluent. A disfluent typeface, on the other hand, may be italicized, presented in greyscale rather than black, and have serifs.

The disfluency effect (Geller, 2017) states that words presented in a disfluent typeface are better remembered than words presented in a more fluent typeface. A long encoding duration has been associated with the disfluency effect (Gomez & Perea, 2014; Ngiam, L. C. Khaw, Holcombe, & Goodbourn, 2018). Ngiam and colleagues suggest that the encoding of disfluent typefaces requires more time for the information to fill WM than fluent typefaces, and Gomez and Perea's study suggests this may be due to a decrease in lexical accessibility for less familiar word forms (in their case, word orientation). Additionally, increased neural activity is seen with decreased typeface fluency during processing (Thiessen et al., 2015). This is due to the fact that a disfluent typeface requires more mental effort and better understanding of the content in order for the information to be successfully encoded into WM (Eitel, Kühn, Scheiter, & Gerjets, 2014; Thiessen et al., 2015). In fact, if a typeface is more disfluent, deeper processing could occur due to enhanced recall (Price, McElroy, & Martin, 2016). Typeface fluency has been shown to impact iconic storage capacity (Hoffman, 1987). Moreover, Ngiam and colleagues (2018) found a decreased verbal WM capacity for disfluent typefaces, and Rajsic, Burton, and Woodman (2019) found that written letters and words activate visual WM encoding and storage. In addition, Walker (2008) found that letter and word identification is supported by encoding the visual aspects of written language. Various

aspects of typeface have also been found to influence attention (Faber, Mills, Kopp, & D'Mello, 2017). Brath and Banissi (2017) suggest that typeface spacing is perceived preattentively and note that it can specifically influence the encoding of quantitative information. Roldán, Marcet, and Perea (2018) found that letter segmentation – the separation of words into individual letters – occurs during the letter encoding stage of written language encoding. This is called cursive normalisation. The study found that connected letters in cursive typefaces require a longer reaction time than for typefaces with separated letters. Geller (2017) additionally found that the more disfluent a cursive text is, the better it is remembered.

As much as there is evidence in support of the disfluency effect, there is also some evidence with contrasted findings. Larson (2009) suggested that visual aid variables such as varying typeface do not have any significant impact on information recall. Instead, their study suggests that unfamiliarity with the disfluent typeface, rather than the disfluency itself, impacts encoding. This has been backed up by several studies that suggested perceptual disfluency may even have a negative impact on memory (Einstein, McDaniel, Owen, & Côté, 1990; Yue, Castel, & Bjork, 2013). It is possible that there is an existing threshold for any beneficial disfluency effects. It is therefore important for future research to identify the amount of perceptual difficulty required to be beneficial to memory. This threshold is called desirable difficulty (Bjork, 1994). According to Bjork (1994), desirable difficulties force the reader to use a more elaborate encoding processes, as well as a more substantial and varied retrieval processes. Perceptual difficulties that sit below this threshold trigger encoding and retrieval processes that support the processing and recall of novel information (Bjork & Bjork, 2011). Sungkhasettee, Friedman, and Castel (2011) show that desirable difficulties in word presentation increases recall success, as they require encoding processes that enhance recall. This is therefore something that must be kept in mind when studying the effects of

disfluency not only on the encoding process, but also on recall ability. Bryden and Allard (1976) suggest that typeface processing is carried out more efficiently in the right hemisphere. They found that script-like (more disfluent) typefaces showed left hemisphere dominance, whereas print-type (more fluent) typefaces were associated with greater right hemisphere activity. Moreover, the initial stages of written letter processing has been associated with right hemispheric dominance (Hellige & Webster, 1979).

On balance, the findings on typeface fluency suggest that both visual and linguistic based aspects of written language play a role in encoding. However, there is still more to learn about what factors contribute to beneficial effects, as well as understand the neural mechanisms of such effects.

The Present Study

Much of the typeface fluency and encoding research focuses on single letters or words, rather than on full sentences. Since most of our communication occurs in full sentences, the study of typeface fluency impact on sentence encoding would be highly beneficial. This study will aim to fill this gap in the current literature by focusing specifically on the encoding of written sentences. There is equally a gap in terms of measuring the influence of typeface on sentence encoding with EEG. As alpha power appears to be important for the sensory aspects of language processing (Weiss & Mueller, 2003), attention (Mathewson et al., 2011), task difficulty (Geske & Bellur, 2008) and cognitive performance (Klimesch et al., 2007), it will be used as a measure of encoding success. Additionally, theta frequencies are important for memory (White et al., 2013) and language encoding (Bastiaansen & Hagoort, 2006). Theta power has also been specifically associated with sentence encoding (Lam et al., 2016) and will therefore also be analysed. Finally, simultaneous alpha ERD and theta ERS are associated with information processing (Mölle et al., 2002), and therefore their relationship will be taken into account.

The aims of the study are therefore to determine whether:

1. Encoding of written sentences can be measured via alpha ERD and theta ERS
2. Encoding of sentences is influenced by typeface fluency
3. Alpha and theta power levels during encoding are indicative of recall outcome

From these aims, it is predicted that:

1. A lower alpha power and higher theta power will imply stronger encoding of written information, when compared to baseline power levels
2. Encoding of sentences in a disfluent typeface will be associated with greater change in alpha and theta power from a baseline, relative to sentences in a fluent typeface
3. A disfluent typeface will be associated with superior information recall.

Method

Participants

Power analysis based on effects of typeface on early attention processes, as reported by Keage et al (2015) determined that 14 participants would be adequate, assuming a large effect size ($f = .47$) at power = .90, alpha = .05. To account for potential variations in effect and data loss, as well as provide sufficient data for averaging EEG effects, we aimed to recruit up to 40 participants. Forty-nine participants were initially recruited, with 35 undergraduate students (23 female, 12 male) from the University of Adelaide aged 18-34 ($M = 20.59$, $SD = 3.32$) completing the study. Participants were recruited either via an online portal to obtain course credit, or in response to fliers placed on campus and a \$40 gift voucher for their participation.

Inclusion criteria contained:

- Right-handed (due to differential effects of handedness on EEG recordings (Galín, Ornstein, Herron, & Johnstone, 1982)).
- English as their primary spoken language
- Have normal or corrected to normal vision
- No current psychiatric, neurological or learning/intellectual disorder
- No current or previous alcohol or substance abuse or dependence
- No history of unconsciousness for greater than one minute (except due to anaesthetic)
- No recreational drug use in the last six months

The present study used a within-subjects design, with the presentation order of fluent and disfluent typefaces being pseudorandomised to control for any order effects. The University of Adelaide Human Research Ethics Committee approved this study.

Materials

Alien Species task. For the main task of the study, participants were asked to read a series of simple sentences describing two alien species. Both species has a name and seven features to memorise. These features differed between the species by only one word. For example, “*has thick, tough skin*” versus “*has thick, tough scales*”. A full list of sentences can be found in *Appendix A*. The information was shown electronically, in either a fluent or disfluent typeface. The fluent typeface was *Arial*, and the disfluent typeface was *Bodoni MT* italicized and in 60% greyscale. Both typefaces were displayed in 12pt size. This task has been adapted from a study conducted by Diemand-Yauman, Oppenheimer, and Vaughan (2011), which looked at the impact of typeface fluency on the processing of individual letters.

In addition to the Alien Species task, three tasks were used as distractor tasks. These were carried out in a 15-minute timeslot between the learning and recall stages of the main task. The roles of two tasks in the study were to prevent the participant from engaging in active rehearsal of the Alien Species information, and the results of the distractor tasks were not presented in this report. The results of the one-back task were compared to the participants’ behavioural outcomes of the main task to consider the impact of general attentional state and ability on language processing. The order of distractor task presentation was counterbalanced to avoid any order effects.

One-back Task. In this task, letters will be shown individually, in either a fluent (*Arial* or *Times New Roman*) or disfluent (*Edwardian Script* or *Lucinda Blackletter*) typeface, on the computer screen. These letters are matched by visual size, rather than font point. The participant must determine whether the letter presented is the same as the one before. Stimuli were presented for 500ms, and the inter-stimulus intervals varied between 1250ms and 1750ms. The probability of a repetition in stimuli was 38%. One-back tasks are used to measure WM (Conway et al., 2005) and attention (Nebel et al., 2005), and thus was

chosen as a distractor. Additionally, the one-back task was used as a comparison measure for recall ability. This task ran for approximately five minutes.

Raven's Progressive Matrices (RPM). This general intelligence task focuses on visual similarity (Kunda, McGreggor, & Goel, 2009) and thus it was used as a distractor after the one-back task. For RPM, the participant is asked to identify the missing piece of a design or pattern out of either six or eight options (Raven, 2000). The designs get progressively more complex throughout the task. The participants were given the first five sets of the general RPM and were asked to complete as much as they could within a time limit of ten minutes following the completion of the one-back task.

Group Embedded Figure Test (GEFT). The participant must locate a simple figure inside a more complex one (Day, McRae, & Young, 1990). The GEFT comprises of three sections. The first section contains seven relatively simple items and is primarily for practice. The second and third sections each contain nine items. This distractor task was chosen due to the fact that it assesses level of field dependence-independence, or the degree to which a person can make perceptual judgements about stimuli without contextual cues from the field (Donovan, Queisser, & O'leary, 1976). This is useful as it may provide some insight into whether participants can remove cues such as fluency from their perception of the presented text. The participants were given 15 minutes to complete this task.

Apparatus

SCAN4.5 software (Compumedics Neuroscan) was used to monitor brain activity. Electroencephalography was obtained using a modified Quik-Cap (Compumedics Neuroscan, Charlotte, North Carolina, USA) with the 64 silver/silver-chloride electrodes positioned according to the 10-20 system (American Electroencephalographic Society, 1994). Participants were seated in a lit testing room, approximately 60 cm from the monitor that presented the stimuli. The signal was collected and referenced to Cpz with an Apz ground,

and all EEG data were re-referenced offline to an average mastoids reference prior to further analysis. Vertical and horizontal eye movements were recorded in bipolar channels with electrodes 1 cm above and below the left eye and from the outer canthus of each eye.

Continuous EEG was recorded using a Synamps II amplifier (Compumedics Neuroscan) that sampled the analogue signal at 1000 Hz with an analogue bandpass filter between 0.1 and 100 Hz. Impedance at each electrode was reduced to below 5 K Ω at the start of recording.

Procedure

We first welcome the participant and ask them to read and sign a consent form, before applying the appropriate size EEG cap in the test room, where the participant remained for the duration of the study. The task then consisted of four phases: the baseline, the learning phase, the distractor phase and the recall phase.

1. Baseline. The participant spends two minutes sitting with their eyes open, and two minutes with their eyes closed. Brain activity was recorded during this phase and the first one minute was used as a baseline comparison for alpha power levels during the learning phase.

2. Learning Phase. The information on the two alien species was shown electronically for 60 seconds in either the fluent (Arial) or disfluent (Bodoni MT) typeface. During this time, the participant attempted to memorise as much of the information as possible.

3. Distractor Phase. The participant was given 15 minutes to complete the GEFT or both the one-back task and RPM.

4. Recall Phase. The participant was presented with the 56 audio file statements, presented using free field speakers located on each side of the monitor. The order of the statements was pseudorandomised to avoid any order effects. The participants chose which alien each statement is related to, pressed one of the two response buttons that had been pre-assigned as the first or second alien presented.

Phases two, three and four were repeated with the counter-condition typeface and the other distractor. The order of their presentation was counterbalanced to control for any order effects of fluency or influence from the distractor task.

Following the second recall phase, the participant's QuikCap was removed and cleaned. The participant had the opportunity to wash their hair before leaving the laboratory.

Data Analysis

Independent components analysis (ICA) isolates specific artefacts, making it easier to clean and analyse EEG data (Delorme, Sejnowski, & Makeig, 2007; Vigário, 1997), and was used to remove any eye movement, muscle activity or electrical noise from the data. This was done using MATLAB, and the MATLAB toolkit EEGLab (Delorme & Makeig, 2004) was used to extract spectral power from the cleaned data. For analysis, we classified theta as the frequency bandwidth between 4-7Hz, and alpha as the bandwidth between 8-13Hz. These frequencies were isolated over a 60 second period from the eyes open baseline, fluent learning and disfluent learning phases, from the point of stimulus onset. Topographic maps for average overall alpha and theta were constructed using EEGLab to display activity during the fluent and disfluent encoding phases. Previous research has found that alpha activity is most prevalent in the occipital and parietal regions of the brain (Thut & Miniussi, 2009), whereas theta activity is most prevalent in the frontal and parietal regions (Thut, Miniussi, & Gross, 2012). Therefore, electrode channels from these regions were used for statistical analyses (see *figure 1*). A regional analysis was conducted to compare alpha and theta activity in these areas across hemispheres and across fluent and disfluent conditions.

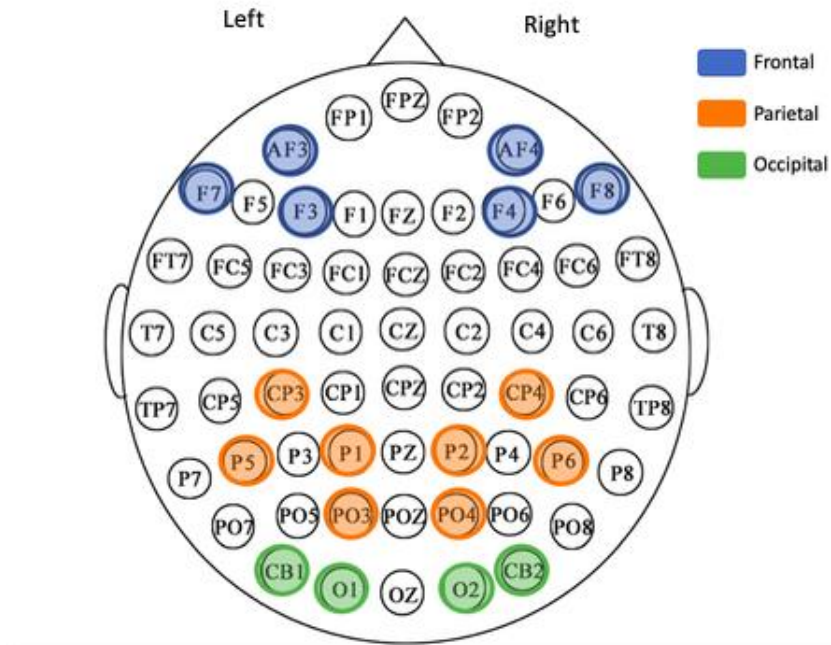


Figure 1. Compumedics Neuroscan 64-channel Quik-Cap electrodes used for regional and hemispheric analysis.

Statistical Analysis

We hypothesise that changes in alpha and theta power will occur during simple sentence encoding. Further, we expect that these changes will be greater when encoding information in a disfluent typeface than in a fluent typeface. This is expected to be associated with superior recall outcomes. Behavioural responses were binary (correct or incorrect) and elicited through response buttons. These responses were compared to trigger codes throughout the recall phase and averaged for each fluency condition to find the percentage of correct recall. This was then compared to the responses of the one-back distractor task to determine the accuracy of the recall findings. To analyse the EEG data, relative alpha and theta datasets were first separated for analysis. The fluent and disfluent datasets were then compared to the baseline eyes open values to find the change in spectral power between baseline and encoding. Median scores were calculated for overall alpha and theta power for each participant, and then tested for normality using the Shapiro-Wilk normality test and

histograms in SPSS (IBM Corp, Armonk, New York). Mean comparison tests were then run to determine any initial differences between the fluent and disfluent conditions for both alpha and theta power. To further explore these conditions, the data was analysed using linear mixed models (LMM). LMM was chosen over other analyses due to its ability to control variance without data averaging, and its ability to investigate multiple interactions and effects (Steson & Sally, 2015). The LMM analysis for spectral power included fluency (fluent vs disfluent), hemisphere (left vs right), and region (frontal, parietal, occipital) as fixed factors, and participant was included as a random intercept. LMM analyses were conducted separately for alpha and theta power. Significance was determined at $p < .05$.

Results

Due to technological difficulties during data cleaning, four of the 35 data sets could not be used for analysis. Therefore, the final analysis was performed on 31 participants (10 male and 21 female).

Behavioural Analysis

Analysis of recall data showed a strong ceiling effect. Participants averaged an error rate of only 1.4% overall, with an average correct disfluent score of 97.8% ($SD = 4.93\%$) and average correct fluent score of 98.7% ($SD = 3.46\%$). To check whether this was an accurate representation of recall, we compared these outcomes with that of the one-back task. The one-back also had a very high correct response rate ($M = 89.66\%$, $SD = 9.23\%$), which replicates the response rate found by Keage et al. (2014) on the same task and suggests the high correct response rate was an accurate representation of the participants' attention and recall abilities. Because of this ceiling effect, we were unable to determine the impact of fluency on recall success. Thus, the following results from spectral analysis focus on the differences in encoding activity only.

Spectral Analysis

Global alpha and theta activity for both the fluent and disfluent conditions were first visualised using topographic maps (see *figures 2 and 3*). Activity was averaged across the 31 participants for analysis. These provided preliminary evidence for spectral activity differences between conditions.

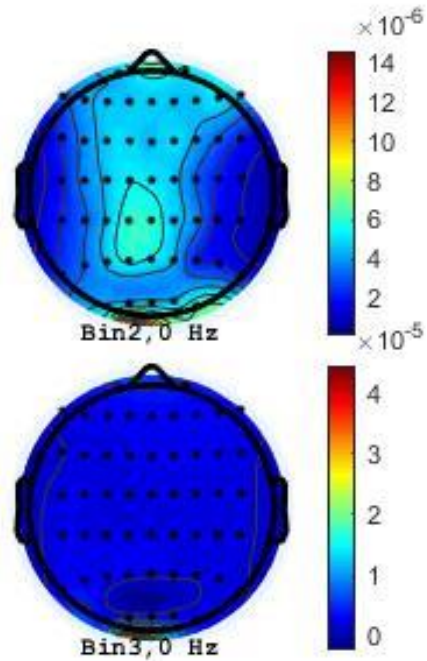


Figure 2. Average alpha activity during the encoding phase for fluent (top) and disfluent (bottom) conditions.

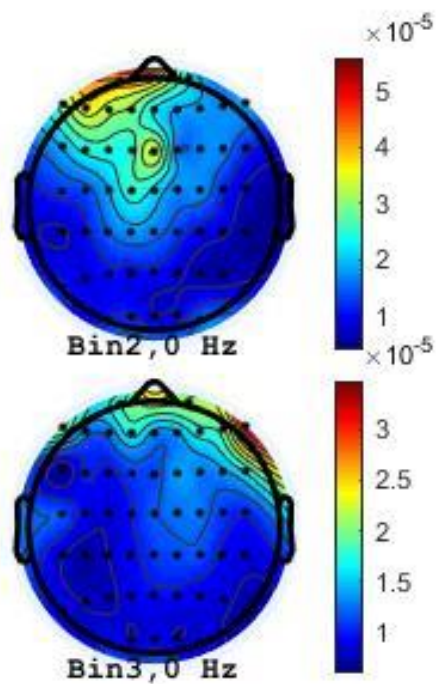


Figure 3. Average theta activity during the encoding phase for fluent (top) and disfluent (bottom) conditions.

For alpha power relative to the eyes open baseline, the disfluent condition contained a higher median power score (4.89×10^{-4} , range = -0.003-0.007) than the fluent condition (-2.43×10^{-5} , range = -0.005-0.009). Similarly, we found a greater median power of for the disfluent condition (5.54×10^{-4} , range = -0.012-0.011) than the fluent dataset (8.55×10^{-5} , range = -0.005-0.003) in the theta frequency band. Visual inspection of histograms revealed the fluent groups to have a negative skew, and the disfluent groups to have approximately normal distributions. Additionally, the Shapiro-Wilk normality test showed a non-normal distribution for fluent alpha ($W = .914$, $p = .017$), but normal distributions with outliers for the other conditions (disfluent alpha: $W = .935$, $p = .061$, fluent theta: $W = .968$, $p = .461$, disfluent theta: $W = .960$, $p = .286$). Due to the skewness and outliers, a Wilcoxon signed-ranks test was used to compare spectral data across fluent and disfluent conditions. This analysis found a significant difference between fluent and disfluent conditions in the alpha power band, $z = 142$, $p = .038$, but not in the theta power band, $z = 201$, $p > .05$. These comparisons are presented in *figures 4 and 5*.

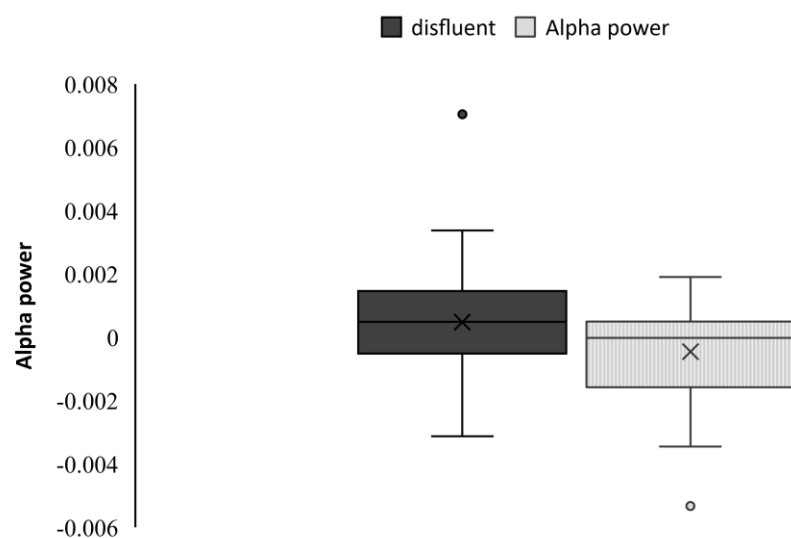


Figure 4. Boxplot of alpha power relative to baseline eyes open across fluent and disfluent conditions.

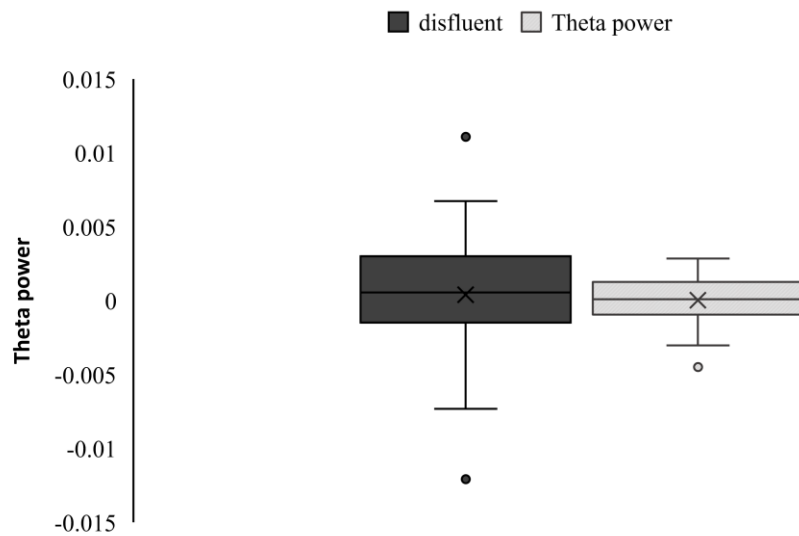


Figure 5. Boxplot of theta power relative to baseline eyes open across fluent and disfluent conditions.

A full factorial LMM, using estimated marginal means for pairwise comparisons of alpha power across regions, included fluency, brain region and hemisphere as fixed factors. No covariates were used. Individual participants were entered as a random intercept to control for individual differences. Analysis of fixed effects found a significant difference between regions of the brain, $F(2, 130.706) = 3.226, p = .043$. Pairwise comparisons further explored this regional difference (see *figure 6*) and found significant variance between the parietal and occipital regions (mean difference = 0.003, $p = .012$). However, this analysis found the difference between fluent and disfluent conditions to be non-significant. Additionally, no other regional differences or hemispheric differences were found (see *Appendix B*).

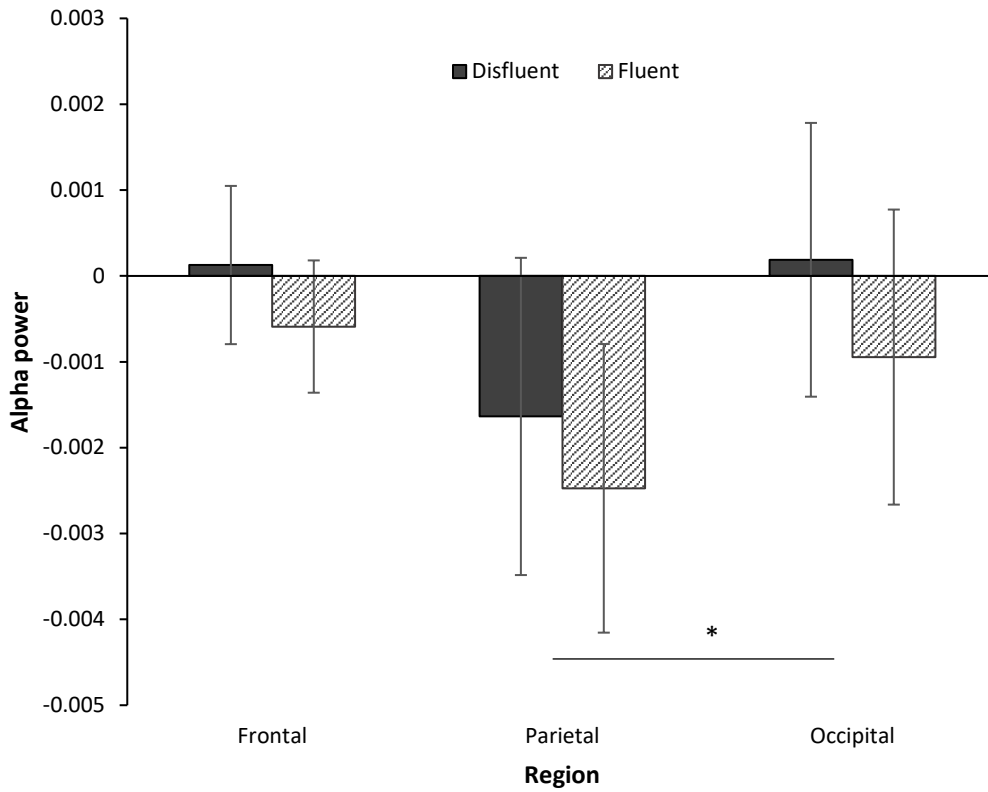


Figure 6. Differences in alpha power between brain regions for fluent and disfluent conditions. * $p < .05$.

Discussion

This study looked at the influence of typeface fluency on written language encoding. We aimed to expand on previous literature by focusing on the processing of simple sentences, rather than on single letters or words. We were particularly interested in quantifying this effect through the analysis of changing spectral power during the encoding phase, as this had not been previously reported. To measure this, we recorded alpha and theta activity using EEG during a memorisation task and focused on changes in power relative to an eyes open baseline for analysis. Based on previous research in the field, it was expected that stronger encoding of written sentences would be shown through alpha desynchronisation and theta synchronisation (hypothesis one), and that there would be greater alpha and theta power changes during the encoding of disfluent information, relative to fluent information (hypothesis two). Additionally, we expected participants to have greater recall success for information presented in the disfluent sentences, relative to the fluent sentences (hypothesis three). The hypotheses were largely unconfirmed, however some differences in alpha power across conditions and regions was observed.

Observations of topographical maps show that the activity in each frequency band was most concentrated in the regions expected based on the literature (Thut & Miniussi, 2009; Thut et al., 2012). Theta activity was primarily found in the frontal regions of the brain, whereas alpha was concentrated in the occipital regions. Activity in each frequency band also differed with fluency condition. While theta in the fluent condition was strongest in the left-central area of the frontal region, the disfluent condition showed more theta activity on the right of the frontal region. Activity in the disfluent condition was also more concentrated to the one area than in the fluent condition. Similarly, alpha activity in the fluent condition was highest in the occipital region but was relatively spread out along the anterior-posterior axis of the brain. Alpha in the disfluent condition, however, was strongly concentrated in the

occipital region, with little activity elsewhere. No hemispheric differences between the fluent and disfluent conditions were apparent. The maps suggest that there is less global activity relative to baseline in the disfluent condition than in the fluent condition for both the theta and alpha bands.

Statistical analyses looked at the overall alpha and theta power in each of the fluency conditions, relative to the baseline eyes open condition. The results showed a significant difference in alpha power relative to typeface fluency. This provides evidence for the link between alpha power and encoding, and the influence of fluency on this connection.

However, alpha synchronisation was found in the disfluent condition, meaning alpha activity increased during the encoding phase relative to baseline. This goes against the hypothesised direction of power change when compared to the baseline and does not replicate the majority of previous research findings. Therefore, hypothesis one was not supported by the findings, and hypothesis two was only partially supported. It is interesting to note that, although the interactions with condition and scalp region were not significant, alpha activity in the parietal region did demonstrate desynchronisation as expected. Due to a large ceiling effect in the behavioural data, spectral power relative to recall accuracy could not be assessed, and thus we could not provide any evidence in support of hypothesis 3. Further analysis focused only on the effects of fluency on alpha power during the encoding phase.

Overall alpha power was found to be significantly different between fluent and disfluent conditions. As expected, alpha power decreased from the baseline for the fluent condition. However, alpha power was found to increase from the baseline for the disfluent condition. Although this goes against the expected direction stated in the hypotheses, an alpha power increase in response to stimuli has been recorded in previous research (Poliakov et al., 2014). This may be explained by distinguishing between induced and evoked alpha activity. While evoked alpha, which is phase locked to the stimulus, synchronises during sensory

information processing, induced alpha, which is not phase locked, desynchronises within the same time window (Klimesch, Doppelmayr, Röhms, Pöllhuber, & Stadler, 2000). David, Kilner, and Friston (2006) note that evoked responses are characterized by the power of the average alpha, whereas induced responses are characterized by the average power that is not explained by the power of the average. As this difference was not focused on or controlled for in this study, doing so in future research may help pinpoint what differences in alpha power occur during encoding of written sentences. Nevertheless, the findings show that alpha power differs due to fluency, which suggests that typeface does play a role in the encoding process.

Although theta appears to be greater in the disfluent condition than in the fluent condition, the difference was not statistically significant. This contradicts the original hypotheses and previous research. This could be due to the fact that a majority of theta differences are found in recall success versus forgetting (Hanslmayr et al., 2008). The ceiling effects (i.e. low forgetting) in this participant pool meant we were unable to establish any recall differences between the fluent and disfluent conditions. ERS of the theta band also tends to be larger during the retrieval of information than during the encoding phase (Klimesch, Schimke, & Schwaiger, 1994). Combined, the observable effects of typeface fluency in the present study may have been confined to the alpha power band as a consequence. Additionally, memory-based theta band activity is commonly found in the hippocampus (Klimesch & Doppelmayr, 1996; Vertes, 2005). Specifically, hippocampal theta has been linked to enhanced learning and memory, and activity is phase locked to stimuli in WM tasks (Kahana, Seelig, & Madsen, 2001). The hippocampus has also recently been specifically associated with language processes, with theta oscillations thought to link the hippocampus and neocortex (Covington & Duff, 2016; Piai et al., 2016). Given EEG only measures electrical activity that reaches the scalp (Teplan, 2002), measures of hippocampal generated theta activity would not be detectable, or would be very indirect at best (Cohen,

2011). This could provide another explanation as to why our theta power findings were non-significant. It is interesting to note, however, that the topographical maps show maximal theta activity in the prefrontal cortex, as research suggests that this area can become synchronised with reverberatory hippocampal activity (Axmacher, Schmitz, Wagner, Elger, & Fell, 2008; Cohen, 2011).

Following this analysis, we no longer focused on theta power due to the lack of significant results, and continued with a LMM focusing only on changes in alpha power. This analysis found no differences based on fluency. However, an exploration of regional variation found a significant difference between the parietal and occipital lobes. Alpha power in the parietal region showed more change from the baseline in both the fluent and disfluent conditions when compared to the occipital region. Alpha power in the parietal region desynchronised from the baseline in both conditions, supporting the hypothesised directional change. These results align with previous research on regional alpha activity (Geske & Bellur, 2008; Thut & Miniussi, 2009) and replicate the findings of Klimesch et al. (1996), who found alpha desynchronisation in the parietal regions of the brain during word encoding. In contrast, alpha power increased in the disfluent condition and decreased in the fluent condition within the occipital region of the brain, which aligns with the results of the Wilcoxon signed-ranks test. Zumer, Scheeringa, Schoffelen, Norris, and Jensen (2014) note that an increase in occipital alpha activity suppresses the encoding of irrelevant visual information, whereas a decrease in occipital alpha activity allows relevant visual information to be processed. Applying these findings to the present study's results suggest that alpha ERS may have occurred in the occipital region in the disfluent condition in order to suppress disfluent features of the text, as they were not relevant for information processing.

The regional difference did not interact with hemispheres, and no further hemispheric differences were found overall. Due to the hemispheric specialization of language (Hervé,

Zago, Petit, Mazoyer, & Tzourio-Mazoyer, 2013), it was expected that the left hemisphere would show greater power differences than the right during the encoding process. This could be due to having a relatively small sample size for a full factorial LMM, and therefore being underpowered. The complexity of this model may have reduced the power enough to shadow any significant interactions between factors. In order to fully analyse all interactions using a LMM, a larger sample size would be required. This could increase the power to a level appropriate for complex analysis. Future studies could also increase the number of electrodes used for analysis. Although we used a 64 channel cap and all electrodes were included in the global analysis, only 20 electrode channels were included in the LMM. On top of increasing sample size, running the analysis with the full 64 channels, or increasing the number to a 128 channel cap, could minimize signal loss due to pre-processing, and thus increase the amount of data available for analysis. As the removal of artefacts was done by eye, increasing the number of channels used would also decrease the amount of artefact or lost data due to human error, as well as more precisely isolate components of artefact for rejection.

Another limitation of this study was the lack of variance in recall. Due to the participants getting very few responses incorrect, we were unable to assess the third hypothesis – that a disfluent typeface will increase recall success. However, the large proportion of correct responses with this task and sample of university students replicates other research (Komes, Schweinberger, & Wiese, 2014). Based on this, it would be beneficial for future research to look into the lack of recall difference. Additionally, future studies could use more complex texts, more complex disfluent typefaces, or increase the distractor time in order to measure any potential differences in recall between fluent and disfluent texts.

Further research also ought to look at individual alpha frequencies (IAF) as another method of comparison. EEG activity can differ from person to person, and alpha activity has become a way to index these individual differences (Goljahani et al., 2012). Klimesch,

Schimke, and Pfurtscheller (1993) note that a higher IAF is associated with better recall performance on a memory task. Additionally, they state that IAF can be influenced by demands of attention. Further, changes in IAF are observed during the encoding and recall phases of visual memory tasks (Klimesch, 1997). It could therefore be a beneficial way to measure changes in alpha activity during sentence encoding, and better control for any individual differences.

Additionally, extending the tasks to more complex real-life scenarios, for example reading whole chapters rather than a selection of simple sentences, could increase the generalisability of this type of research to all levels of education. Moreover, there has been research into the relationship between alpha, theta and gamma oscillations (Friese et al., 2013; Palva, Palva, & Kaila, 2005). As gamma frequencies have been associated with feature binding and working memory (Palva et al., 2005), it may be beneficial for future studies to take gamma ERS into account when discussing the impact of typeface fluency on learning. However, a lot of muscle artefact occurs within the gamma frequency range, making it difficult to get a clear and accurate reading through EEG (Fries, Scheeringa, & Oostenveld, 2008). Therefore, intracortical EEG or MEG could be more useful than normal EEG for studying frequencies in the gamma range (Kaiser & Lutzenberger, 2005). Measures such as these could also be used to measure any hippocampal theta activity during encoding, however such techniques are expensive or limited to particular clinical samples. Lastly, to improve the generalisability of typeface fluency research, it would be beneficial to conduct research using a range of population samples. At present, a majority of research in this area has worked with university populations. Conducting similar studies using child, adolescent or clinical samples would substantially increase the generalisability of research in this field, and potentially target populations where understanding factors which influence language processing are likely to have greater benefits.

Although the LMM did not provide any further evidence for the impact of fluency on encoding, it did highlight the regional differences in alpha activity during encoding. Comparing these regions has not been a focus of previous research, and instead they have been analysed as one region (Geske & Bellur, 2008) or separately (Meyer et al., 2013; Thut, Nietzel, Brandt, & Pascual-Leone, 2006). Therefore, this study highlights a new path for future research to take. Moreover, the findings of the Wilcoxon tests support past research on the connection between alpha power and the encoding of written language (M. C. M. Bastiaansen et al., 2002; Klimesch, 1999; Klimesch et al., 1996; Vassileiou et al., 2018; Weiss & Mueller, 2003), but did not replicate findings associated with theta power (Klimesch et al., 2011; Mölle et al., 2002; Werkle-Bergner et al., 2006). They specifically show that alpha power is impacted by typeface fluency during the encoding stage of written simple sentence processing. As there is little research on alpha power and the impact of typeface on sentence encoding at present, this study has begun to fill this gap in the literature. As previously mentioned, different frequency levels of alpha have been associated to different aspects of information processing (Klimesch, 1999). Klimesch (1999) states that while lower frequency alpha is related to attention, higher frequency alpha activity is involved in sensory aspects of processing. Separating alpha into high and low frequencies may highlight differences in fluency impact that are not observable in a wide frequency band and would therefore be a logical next step to take in research.

These results are perhaps most relevant to educational settings, as most educational content is now presented in either a digitised or printed form. Although typeface research can also be applied to marketing and logo design (Childers & Jass, 2002), education is the main area to which this research can be applied, due to the specificity of looking at sentence encoding. There are a number of ways in which typeface fluency plays a role in the educational field. For example, Tarasov, Sergeev, and Filimonov (2015) reviewed the

different typefaces used in textbooks, and noted that not only does the legibility of the typeface used impact reading comprehension and speed, but features such as size, line width, the contrast between text and background colour, and paragraph uniformity. Additionally, Čerepinko, Periša, and Keček (2017) looked at the differences in text legibility between iPad screens, computer screens and paper. They found that a sans serif typeface was more legible and readable on the iPad screen than a more disfluent, serif typeface. Further, they established that text is more readable on paper than on screen. Due to the increased use of technology in education (Selwyn, 2014), it is important to take into account the medium on which text is presented and assess the impact. Čerepinko and colleagues' paper suggests that both typeface fluency and medium can impact the legibility of text. The present study displayed text on a computer screen and found that typeface fluency impacts encoding. Future research could expand on these findings by using spectral power changes to assess the influence of typeface fluency on sentence encoding across a variety of mediums (digital screen and paper). This would be beneficial in today's digitised society.

As mentioned previously, running studies with a range of populations such as different age groups and educational levels would further increase the generalisability of findings in this field. Although there is place in traditional education settings as mentioned above, there is also cause for applying research on the impact of typeface to clinical settings. Text presentation has a significant impact on the accessibility of written work for persons with reading difficulties. Previous work in this field has focused on analysing and designing typefaces for persons with vision impairment (Evet & Brown, 2005), aphasia (Rose, Worrall, Hickson, & Hoffmann, 2012) and dyslexia (Hillier, 2008). Rello and Baeza-Yates (2016) note that features such as italicisation decrease reading performance in persons with dyslexia. This suggests that the features used for desirable difficulty differs between normal and clinical populations. While italicisation is possibly a beneficial disfluent feature for typical

population samples (Lonsdale, 2014), it would cross the threshold for desirable difficulty in dyslexic samples. Using spectral power to determine the level of disfluency required for desirable difficulty in both typical and clinical populations would be an interesting expansion on these findings.

While the present study worked with healthy participants and did not show any behavioural differences, the findings regarding alpha activity and regional variation provide evidence for specific underlying mechanisms associated with written language encoding. We have shown that alpha power differences are apparent between fluent and disfluent typefaces, and that this is true not only for individual letters or words, but for full sentences. Further, we have provided evidence for regional differences in alpha activity during written language encoding. Such research will aid in the understanding language processing, as well as provide a platform or future research to extend not only the understanding of processing in typical populations, but also in clinical conditions with impairment in visual language processing.

To conclude, the present study provides further evidence for alpha power being associated with encoding success. It has expanded on previous literature by analysing alpha power during sentence encoding rather than at an individual letter or word level. Moreover, it showed that changes in alpha power differ between fluent and disfluent typeface conditions, therefore suggesting that typeface fluency impacts encoding. This research can be applied to educational fields of work and research, as much academic language processing now occurs through written text.

References

- Allen, P. A., Madden, D. J., & Slane, S. (1995). Visual word encoding and the effect of adult age and word frequency. In P. A. Allen & T. R. Bashore (Eds.), *Advances in Psychology* (Vol. 110, pp. 30-71): North-Holland.
- American Electroencephalographic Society. (1994). Guideline thirteen: Guidelines for standard electrode position nomenclature. *Journal of Clinical Neurophysiology*, *11*(1), 111-113.
- Axmacher, N., Schmitz, D. P., Wagner, T., Elger, C. E., & Fell, J. (2008). Interactions between Medial Temporal Lobe, Prefrontal Cortex, and Inferior Temporal Regions during Visual Working Memory: A Combined Intracranial EEG and Functional Magnetic Resonance Imaging Study. *The Journal of Neuroscience*, *28*(29), 7304.
doi:10.1523/JNEUROSCI.1778-08.2008
- Bacigalupo, F., & Luck, S. J. (2019). Lateralized Suppression of Alpha-Band EEG Activity As a Mechanism of Target Processing. *The Journal of Neuroscience*, *39*(5), 900.
doi:10.1523/JNEUROSCI.0183-18.2018
- Baddeley, A. D. (1976). *The psychology of memory*. New York.
- Baldo, J. V., Kacinik, N., Ludy, C., Paulraj, S., Moncrief, A., Piai, V., . . . Dronkers, N. F. (2018). Voxel-based lesion analysis of brain regions underlying reading and writing. *Neuropsychologia*, *115*, 51-59.
doi:https://doi.org/10.1016/j.neuropsychologia.2018.03.021
- Barton, J. J., Fox, C. J., Sekunova, A., & Iaria, G. (2010). Encoding in the visual word form area: An fMRI adaptation study of words versus handwriting. *Journal of Cognitive Neuroscience*, *22*(8), 1649-1661.
- Barton, J. J. S., Sekunova, A., Sheldon, C., Johnston, S., Iaria, G., & Scheel, M. (2010). Reading words, seeing style: The neuropsychology of word, font and handwriting

perception. *Neuropsychologia*, 48(13), 3868-3877.

doi:<https://doi.org/10.1016/j.neuropsychologia.2010.09.012>

Bastiaansen, M., & Hagoort, P. (2003). Event-Induced Theta Responses as a Window on the Dynamics of Memory. *Cortex*, 39(4), 967-992. doi:[https://doi.org/10.1016/S0010-9452\(08\)70873-6](https://doi.org/10.1016/S0010-9452(08)70873-6)

Bastiaansen, M., & Hagoort, P. (2006). Oscillatory neuronal dynamics during language comprehension. In C. Neuper & W. Klimesch (Eds.), *Progress in Brain Research* (Vol. 159, pp. 179-196): Elsevier.

Bastiaansen, M., Van Berkum, J., & Hagoort, P. (2002). Event-related theta responses in the human EEG during online sentence processing. *Neuroscience Letters*, 324, 121-124.

Bastiaansen, M. C. M., Oostenveld, R., Jensen, O., & Hagoort, P. (2008). I see what you mean: Theta power increases are involved in the retrieval of lexical semantic information. *Brain and Language*, 106(1), 15-28.
doi:<https://doi.org/10.1016/j.bandl.2007.10.006>

Bastiaansen, M. C. M., van Berkum, J. J. A., & Hagoort, P. (2002). Event-related theta power increases in the human EEG during online sentence processing. *Neuroscience Letters*, 323(1), 13-16. doi:[https://doi.org/10.1016/S0304-3940\(01\)02535-6](https://doi.org/10.1016/S0304-3940(01)02535-6)

Beier, S. (2013). Legibility investigations: controlling typeface variables.

Bjork, E. L., & Bjork, R. A. (2011). Making things hard on yourself, but in a good way: Creating desirable difficulties to enhance learning. *Psychology and the real world: Essays illustrating fundamental contributions to society*, 2(59-68).

Bjork, R. A. (1994). Memory and metamemory considerations in the training of human beings. *Metacognition: Knowing about knowing*, 185.

- Brath, R., & Banissi, E. (2017). Font attributes enrich knowledge maps and information retrieval. *International Journal on Digital Libraries*, 18(1), 5-24. doi:10.1007/s00799-016-0168-4
- Bryden, M. P., & Allard, F. (1976). Visual hemifield differences depend on typeface. *Brain and Language*, 3(2), 191-200. doi:https://doi.org/10.1016/0093-934X(76)90016-X
- Carter, R., Meggs, P. B., & Day, B. (2011). *Typographic Design: Form and Communication* (5 ed.): Wiley.
- Čerepinko, D., Periša, M., & Keček, D. (2017). Text readability and legibility on iPad with comparison to paper and computer screen. *Tehnički vjesnik*, 24(4), 1197-1201.
- Childers, T. L., & Jass, J. (2002). All Dressed Up With Something to Say: Effects of Typeface Semantic Associations on Brand Perceptions and Consumer Memory. *Journal of Consumer Psychology*, 12(2), 93-106. doi:10.1207/s15327663jcp1202_03
- Clark, D., & Wagner, A. D. (2003). Assembling and encoding word representations: fMRI subsequent memory effects implicate a role for phonological control. *Neuropsychologia*, 41(3), 304-317. doi:https://doi.org/10.1016/S0028-3932(02)00163-X
- Cohen, Michael X. (2011). Hippocampal-Prefrontal Connectivity Predicts Midfrontal Oscillations and Long-Term Memory Performance. *Current Biology*, 21(22), 1900-1905. doi:https://doi.org/10.1016/j.cub.2011.09.036
- Conway, A. R. A., Kane, M. J., Bunting, M. F., Hambrick, D. Z., Wilhelm, O., & Engle, R. W. (2005). Working memory span tasks: A methodological review and user's guide. *Psychonomic Bulletin & Review*, 12(5), 769-786. doi:10.3758/bf03196772
- Covington, N. V., & Duff, M. C. (2016). Expanding the Language Network: Direct Contributions from the Hippocampus. *Trends in cognitive sciences*, 20(12), 869-870. doi:https://doi.org/10.1016/j.tics.2016.10.006

- David, O., Kilner, J. M., & Friston, K. J. (2006). Mechanisms of evoked and induced responses in MEG/EEG. *NeuroImage*, *31*(4), 1580-1591.
- Day, D. A., McRae, L. S., & Young, J. D. (1990). The group embedded figures test: A factor analytic study. *Perceptual and Motor Skills*, *70*(3), 835-839.
- Delorme, A., & Makeig, S. (2004). EEGLAB: an open source toolbox for analysis of single-trial EEG dynamics including independent component analysis. *Journal of Neuroscience Methods*, *134*(1), 9-21.
doi:<https://doi.org/10.1016/j.jneumeth.2003.10.009>
- Delorme, A., Sejnowski, T., & Makeig, S. (2007). Enhanced detection of artifacts in EEG data using higher-order statistics and independent component analysis. *NeuroImage*, *34*(4), 1443-1449. doi:<https://doi.org/10.1016/j.neuroimage.2006.11.004>
- Diemand-Yauman, C., Oppenheimer, D. M., & Vaughan, E. B. (2011). Fortune favors the bold (and the Italicized): effects of disfluency on educational outcomes. *Cognition*, *118*(1), 111-115. doi:[10.1016/j.cognition.2010.09.012](https://doi.org/10.1016/j.cognition.2010.09.012)
- Donovan, D. M., Queisser, H. R., & O'leary, M. R. (1976). Group Embedded Figures Test performance as a predictor of cognitive impairment among alcoholics. *International Journal of the Addictions*, *11*(5), 725-739.
- Einstein, G. O., McDaniel, M. A., Owen, P. D., & Côté, N. C. (1990). Encoding and recall of texts: The importance of material appropriate processing. *Journal of Memory and Language*, *29*(5), 566-581. doi:[https://doi.org/10.1016/0749-596X\(90\)90052-2](https://doi.org/10.1016/0749-596X(90)90052-2)
- Eitel, A., Kühn, T., Scheiter, K., & Gerjets, P. (2014). Disfluency Meets Cognitive Load in Multimedia Learning: Does Harder-to-Read Mean Better-to-Understand? *Applied Cognitive Psychology*, *28*(4), 488-501. doi:[10.1002/acp.3004](https://doi.org/10.1002/acp.3004)

- Evett, L., & Brown, D. (2005). Text formats and web design for visually impaired and dyslexic readers—Clear Text for All. *Interacting with Computers*, *17*(4), 453-472. doi:10.1016/j.intcom.2005.04.001
- Faber, M., Mills, C., Kopp, K., & D’Mello, S. (2017). The effect of disfluency on mind wandering during text comprehension. *Psychonomic Bulletin & Review*, *24*(3), 914-919. doi:10.3758/s13423-016-1153-z
- Fell, J., Ludowig, E., Staresina, B. P., Wagner, T., Kranz, T., Elger, C. E., & Axmacher, N. (2011). Medial Temporal Theta/Alpha Power Enhancement Precedes Successful Memory Encoding: Evidence Based on Intracranial EEG. *The Journal of Neuroscience*, *31*(14), 5392. doi:10.1523/JNEUROSCI.3668-10.2011
- Fellner, M.-C., Bäuml, K.-H. T., & Hanslmayr, S. (2013). Brain oscillatory subsequent memory effects differ in power and long-range synchronization between semantic and survival processing. *NeuroImage*, *79*, 361-370. doi:https://doi.org/10.1016/j.neuroimage.2013.04.121
- Friederici, A. D. (2004). Event-related brain potential studies in language. *Current Neurology and Neuroscience Reports*, *4*(6), 466-470. doi:10.1007/s11910-004-0070-0
- Fries, P., Scheeringa, R., & Oostenveld, R. (2008). Finding Gamma. *Neuron*, *58*(3), 303-305. doi:https://doi.org/10.1016/j.neuron.2008.04.020
- Friese, U., Köster, M., Hassler, U., Martens, U., Trujillo-Barreto, N., & Gruber, T. (2013). Successful memory encoding is associated with increased cross-frequency coupling between frontal theta and posterior gamma oscillations in human scalp-recorded EEG. *NeuroImage*, *66*, 642-647. doi:https://doi.org/10.1016/j.neuroimage.2012.11.002
- Galin, D., Ornstein, R., Herron, J., & Johnstone, J. (1982). Sex and handedness differences in EEG measures of hemispheric specialization. *Brain and Language*, *16*(1), 19-55. doi:https://doi.org/10.1016/0093-934X(82)90070-0

- Geller, J. (2017). *Would disfluency by any other name still be disfluent? Examining the boundary conditions of the disfluency effect*. (Doctor of Philosophy). Iowa State University, Graduate Theses and Dissertations database. (15520)
- Geske, J., & Bellur, S. (2008). Differences in brain information processing between print and computer screens. *International Journal of Advertising*, 27(3), 399-423.
doi:10.2501/S0265048708080049
- Goljahani, A., D'Avanzo, C., Schiff, S., Amodio, P., Bisiacchi, P., & Sparacino, G. (2012). A novel method for the determination of the EEG individual alpha frequency. *NeuroImage*, 60(1), 774-786. doi:<https://doi.org/10.1016/j.neuroimage.2011.12.001>
- Gomez, P., & Perea, M. (2014). Decomposing encoding and decisional components in visual-word recognition: A diffusion model analysis. *The Quarterly Journal of Experimental Psychology*, 67(12), 2455-2466.
- Grabner, R. H., Brunner, C., Leeb, R., Neuper, C., & Pfurtscheller, G. (2007). Event-related EEG theta and alpha band oscillatory responses during language translation. *Brain Research Bulletin*, 72(1), 57-65.
doi:<https://doi.org/10.1016/j.brainresbull.2007.01.001>
- Grabow, J. D., Aronson, A. E., Greene, K. L., & Offorfd, K. P. (1979). A comparison of EEG activity in the left and right cerebral hemispheres by power-spectrum analysis during language and non-language tasks. *Electroencephalography and Clinical Neurophysiology*, 47(4), 460-472. doi:[https://doi.org/10.1016/0013-4694\(79\)90162-7](https://doi.org/10.1016/0013-4694(79)90162-7)
- Hanslmayr, S., Spitzer, B., & Bäuml, K.-H. (2008). Brain Oscillations Dissociate between Semantic and Nonsemantic Encoding of Episodic Memories. *Cerebral Cortex*, 19(7), 1631-1640. doi:10.1093/cercor/bhn197

- Hasson, U., Nusbaum, H. C., & Small, S. L. (2007). Brain Networks Subservicing the Extraction of Sentence Information and Its Encoding to Memory. *Cerebral Cortex*, *17*(12), 2899-2913. doi:10.1093/cercor/bhm016
- Hellige, J. B., & Webster, R. (1979). Right hemisphere superiority for initial stages of letter processing. *Neuropsychologia*, *17*(6), 653-660. doi:https://doi.org/10.1016/0028-3932(79)90040-X
- Hervé, P.-Y., Zago, L., Petit, L., Mazoyer, B., & Tzourio-Mazoyer, N. (2013). Revisiting human hemispheric specialization with neuroimaging. *Trends in cognitive sciences*, *17*(2), 69-80.
- Hillier, R. (2008). Sylexiad. A typeface for the adult dyslexic reader. *Journal of Writing in Creative Practice*, *1*(3), 275-291. doi:10.1386/jwcp.1.3.275_1
- Hoffman, V. (1987). Effect of Typeface on Iconic Storage Capacity.
- Izquierdo, I., & Medina, J. H. (1997). Memory Formation: The Sequence of Biochemical Events in the Hippocampus and Its Connection to Activity in Other Brain Structures. *Neurobiology of Learning and Memory*, *68*(3), 285-316. doi:https://doi.org/10.1006/nlme.1997.3799
- Jensen, O., & Mazaheri, A. (2010). Shaping Functional Architecture by Oscillatory Alpha Activity: Gating by Inhibition. *Frontiers in Human Neuroscience*, *4*(186). doi:10.3389/fnhum.2010.00186
- Kaan, E. (2007). Event-Related Potentials and Language Processing: A Brief Overview. *Language and Linguistics Compass*, *1*(6), 571-591. doi:10.1111/j.1749-818X.2007.00037.x
- Kahana, M. J. (2006). The cognitive correlates of human brain oscillations. *Journal of Neuroscience*, *26*(6), 1669-1672.

- Kahana, M. J., Seelig, D., & Madsen, J. R. (2001). Theta returns. *Current Opinion in Neurobiology*, 11(6), 739-744. doi:[https://doi.org/10.1016/S0959-4388\(01\)00278-1](https://doi.org/10.1016/S0959-4388(01)00278-1)
- Kaiser, J., & Lutzenberger, W. (2005). Human gamma-band activity: A window to cognitive processing. *NeuroReport*, 16(3), 207-211. Retrieved from https://journals.lww.com/neuroreport/Fulltext/2005/02280/Human_gamma_band_activity__A_window_to_cognitive.1.aspx
- Keage, H., Coussens, S., Kohler, M., Thiessen, M., & Churches, O. (2014). *Investigating letter recognition in the brain by varying typeface: An event-related potential study* (Vol. 88).
- Klimesch, W. (1997). EEG-alpha rhythms and memory processes. *International Journal of Psychophysiology*, 26(1-3), 319-340. doi:10.1016/S0167-8760(97)00773-3
- Klimesch, W. (1999). EEG alpha and theta oscillations reflect cognitive and memory performance: a review and analysis. *Brain Res Brain Res Rev*, 29(2-3), 169-195. Retrieved from <https://www.ncbi.nlm.nih.gov/pubmed/10209231>
- Klimesch, W., & Doppelmayr, M. (1996). Theta band power in the human scalp EEG and the encoding of new information. *NeuroReport*, 7, 1235-1240.
- Klimesch, W., Doppelmayr, M., Röhmer, D., Pöllhuber, D., & Stadler, W. (2000). Simultaneous desynchronization and synchronization of different alpha responses in the human electroencephalograph: a neglected paradox? *Neuroscience Letters*, 284(1), 97-100. doi:[https://doi.org/10.1016/S0304-3940\(00\)00985-X](https://doi.org/10.1016/S0304-3940(00)00985-X)
- Klimesch, W., Doppelmayr, M., Schimke, H., & B., R. (1997). Theta synchronization and alpha desynchronization in a memory task. *Psychophysiology*, 34(2), 169-176. doi:10.1111/j.1469-8986.1997.tb02128.x
- Klimesch, W., Fellinger, R., & Freunberger, R. (2011). Alpha Oscillations and Early Stages of Visual Encoding. *Frontiers in Psychology*, 2(118). doi:10.3389/fpsyg.2011.00118

- Klimesch, W., Russeger, H., Doppelmayr, M., & Pachinger, T. (1998). A method for the calculation of induced band power: implications for the significance of brain oscillations. *Electroencephalography and Clinical Neurophysiology/Evoked Potentials Section*, *108*(2), 123-130. doi:[https://doi.org/10.1016/S0168-5597\(97\)00078-6](https://doi.org/10.1016/S0168-5597(97)00078-6)
- Klimesch, W., Sauseng, P., & Hanslmayr, S. (2007). EEG alpha oscillations: The inhibition–timing hypothesis. *Brain Research Reviews*, *53*(1), 63-88. doi:<https://doi.org/10.1016/j.brainresrev.2006.06.003>
- Klimesch, W., Schimke, H., Doppelmayr, M., Ripper, B., Schwaiger, J., & Pfurtscheller, G. (1996). Event-related desynchronization (ERD) and the Dm effect: does alpha desynchronization during encoding predict later recall performance? *International Journal of Psychophysiology*, *24*(1-2), 47-60.
- Klimesch, W., Schimke, H., & Pfurtscheller, G. (1993). Alpha frequency, cognitive load and memory performance. *Brain Topography*, *5*(3), 241-251. doi:[10.1007/bf01128991](https://doi.org/10.1007/bf01128991)
- Klimesch, W., Schimke, H., & Schwaiger, J. (1994). Episodic and semantic memory: an analysis in the EEG theta and alpha band. *Electroencephalography and Clinical Neurophysiology*, *91*(6), 428-441.
- Koenigs, M., Acheson, D. J., Barbey, A. K., Solomon, J., Postle, B. R., & Grafman, J. (2011). Areas of left perisylvian cortex mediate auditory-verbal short-term memory. *Neuropsychologia*, *49*(13), 3612-3619. doi:[10.1016/j.neuropsychologia.2011.09.013](https://doi.org/10.1016/j.neuropsychologia.2011.09.013)
- Komes, J., Schweinberger, S., & Wiese, H. (2014). Fluency Affects Source Memory for Familiar Names in Younger and Older Adults: Evidence from Event-related Brain Potentials. *NeuroImage*, *92*. doi:[10.1016/j.neuroimage.2014.02.009](https://doi.org/10.1016/j.neuroimage.2014.02.009)

- Kunda, M., McGregor, K., & Goel, A. (2009). *Addressing the Raven's Progressive Matrices test of "general" intelligence*. Paper presented at the 2009 AAAI Fall Symposium Series.
- Lam, N. H. L., Schoffelen, J.-M., Uddén, J., Hultén, A., & Hagoort, P. (2016). Neural activity during sentence processing as reflected in theta, alpha, beta, and gamma oscillations. *NeuroImage*, *142*, 43-54. doi:<https://doi.org/10.1016/j.neuroimage.2016.03.007>
- Larson, R. B. (2009). Enhancing the recall of presented material. *Computers & Education*, *53*(4), 1278-1284.
- Lin, J.-J., Rugg, M. D., Das, S., Stein, J., Rizzuto, D. S., Kahana, M. J., & Lega, B. C. (2017). Theta band power increases in the posterior hippocampus predict successful episodic memory encoding in humans. *Hippocampus*, *27*(10), 1040-1053.
doi:10.1002/hipo.22751
- Lonsdale, M. (2014). Typographic features of text. Outcomes from research and practice. *Visible Language*, *48*(3), 29-67.
- Mathewson, K., Lleras, A., Beck, D., Fabiani, M., Ro, T., & Gratton, G. (2011). Pulsed Out of Awareness: EEG Alpha Oscillations Represent a Pulsed-Inhibition of Ongoing Cortical Processing. *Frontiers in Psychology*, *2*(99). doi:10.3389/fpsyg.2011.00099
- McCandliss, B. D., Cohen, L., & Dehaene, S. (2003). The visual word form area: expertise for reading in the fusiform gyrus. *Trends in cognitive sciences*, *7*(7), 293-299.
doi:[https://doi.org/10.1016/S1364-6613\(03\)00134-7](https://doi.org/10.1016/S1364-6613(03)00134-7)
- Mei, L., Xue, G., Chen, C., Xue, F., Zhang, M., & Dong, Q. (2010). The "visual word form area" is involved in successful memory encoding of both words and faces. *NeuroImage*, *52*(1), 371-378. doi:<https://doi.org/10.1016/j.neuroimage.2010.03.067>

- Meyer, L., Obleser, J., & Friederici, A. D. (2013). Left parietal alpha enhancement during working memory-intensive sentence processing. *Cortex*, *49*(3), 711-721.
doi:<https://doi.org/10.1016/j.cortex.2012.03.006>
- Missonnier, P., Deiber, M.-P., Gold, G., Millet, P., Gex-Fabry Pun, M., Fazio-Costa, L., . . . Ibáñez, V. (2006). Frontal theta event-related synchronization: comparison of directed attention and working memory load effects. *Journal of Neural Transmission*, *113*(10), 1477-1486. doi:10.1007/s00702-005-0443-9
- Mölle, M., Marshall, L., Fehm, H. L., & Born, J. (2002). EEG theta synchronization conjoined with alpha desynchronization indicate intentional encoding. *European Journal of Neuroscience*, *15*(5), 923-928. doi:10.1046/j.1460-9568.2002.01921.x
- Nebel, K., Wiese, H., Stude, P., de Greiff, A., Diener, H.-C., & Keidel, M. (2005). On the neural basis of focused and divided attention. *Cognitive Brain Research*, *25*(3), 760-776. doi:<https://doi.org/10.1016/j.cogbrainres.2005.09.011>
- Ngiam, W., L. C. Khaw, K., Holcombe, A., & Goodbourn, P. (2018). *Visual Working Memory for Letters Varies With Familiarity but Not Complexity*.
- Oppenheimer, D. M., & Frank, M. C. (2008). A rose in any other font would not smell as sweet: Effects of perceptual fluency on categorization. *Cognition*, *106*(3), 1178-1194.
doi:<https://doi.org/10.1016/j.cognition.2007.05.010>
- Paap, K., & C. Ogden, W. (1981). *Letter encoding is an obligatory but capacity-demanding operation* (Vol. 7).
- Palva, J. M., Palva, S., & Kaila, K. (2005). Phase synchrony among neuronal oscillations in the human cortex. *Journal of Neuroscience*, *25*(15), 3962-3972.
- Pfurtscheller, G., & Da Silva, F. L. (1999). Event-related EEG/MEG synchronization and desynchronization: basic principles. *Clinical Neurophysiology*, *110*(11), 1842-1857.

- Pfurtscheller, G., Neuper, C., & Mohl, W. (1994). Event-related desynchronization (ERD) during visual processing. *International Journal of Psychophysiology*, *16*(2), 147-153. doi:[https://doi.org/10.1016/0167-8760\(89\)90041-X](https://doi.org/10.1016/0167-8760(89)90041-X)
- Piai, V., Anderson, K. L., Lin, J. J., Dewar, C., Parvizi, J., Dronkers, N. F., & Knight, R. T. (2016). Direct brain recordings reveal hippocampal rhythm underpinnings of language processing. *Proceedings of the National Academy of Sciences*, *113*(40), 11366. doi:[10.1073/pnas.1603312113](https://doi.org/10.1073/pnas.1603312113)
- Poliakov, E., Stokes, M. G., Woolrich, M. W., Mantini, D., & Astle, D. E. (2014). Modulation of alpha power at encoding and retrieval tracks the precision of visual short-term memory. *Journal of neurophysiology*, *112*(11), 2939-2945.
- Price, J., McElroy, K., & Martin, N. J. (2016). The role of font size and font style in younger and older adults' predicted and actual recall performance. *Aging, Neuropsychology, and Cognition*, *23*(3), 366-388. doi:[10.1080/13825585.2015.1102194](https://doi.org/10.1080/13825585.2015.1102194)
- Rajic, J., Burton, J. A., & Woodman, G. F. (2019). Contralateral delay activity tracks the storage of visually presented letters and words. *Psychophysiology*, *56*(1), e13282.
- Raven, J. (2000). The Raven's Progressive Matrices: Change and Stability over Culture and Time. *Cognitive Psychology*, *41*(1), 1-48. doi:<https://doi.org/10.1006/cogp.1999.0735>
- Rello, L., & Baeza-Yates, R. (2016). The effect of font type on screen readability by people with dyslexia. *ACM Transactions on Accessible Computing (TACCESS)*, *8*(4), 15.
- Röhm, D., Klimesch, W., Haider, H., & Doppelmayr, M. (2001). The role of theta and alpha oscillations for language comprehension in the human electroencephalogram. *Neuroscience Letters*, *310*(2), 137-140. doi:[https://doi.org/10.1016/S0304-3940\(01\)02106-1](https://doi.org/10.1016/S0304-3940(01)02106-1)
- Roldán, M., Marcet, A., & Perea, M. (2018). Is there a cost at encoding words with joined letters during visual word recognition? *Psicológica Journal*, *39*(2), 279-291.

- Rose, T. A., Worrall, L. E., Hickson, L. M., & Hoffmann, T. C. (2012). Guiding principles for printed education materials: Design preferences of people with aphasia. *International journal of speech-language pathology, 14*(1), 11-23.
- Scharinger, C., Kammerer, Y., & Gerjets, P. (2015). Pupil dilation and EEG alpha frequency band power reveal load on executive functions for link-selection processes during text reading. *PloS one, 10*(6), e0130608.
- Schmandt-Besserat, D., & Erard, M. (2008). Origins and forms of writing. *Handbook of research on writing: History, society, school, individual, text, 7-22*.
- Selwyn, N. (2014). *Digital technology and the contemporary university: Degrees of digitization*: Routledge.
- Spironelli, C., & Angrilli, A. (2010). Developmental aspects of language lateralization in delta, theta, alpha and beta EEG bands. *Biological Psychology, 85*(2), 258-267.
doi:<https://doi.org/10.1016/j.biopsycho.2010.07.011>
- Steson, L., & Sally, A. (2015). To transform or not to transform: using generalized linear mixed models to analyse reaction time data. *Frontiers in Psychology, 6*(1171).
doi:[10.3389/fpsyg.2015.01171](https://doi.org/10.3389/fpsyg.2015.01171)
- Sungkhasettee, V. W., Friedman, M. C., & Castel, A. D. (2011). Memory and metamemory for inverted words: Illusions of competency and desirable difficulties. *Psychonomic Bulletin & Review, 18*(5), 973. doi:[10.3758/s13423-011-0114-9](https://doi.org/10.3758/s13423-011-0114-9)
- Tarasov, D. A., Sergeev, A. P., & Filimonov, V. V. (2015). Legibility of Textbooks: A Literature Review. *Procedia - Social and Behavioral Sciences, 174*, 1300-1308.
doi:<https://doi.org/10.1016/j.sbspro.2015.01.751>
- Teplan, M. (2002). Fundamentals of EEG measurement. *Measurement science review, 2*(2), 1-11.

- Thiessen, M., Kohler, M., Churches, O., Coussens, S., & Keage, H. (2015). *Brainy type: a look at how the brain processes typographic information* (Vol. 49).
- Thut, G., & Miniussi, C. (2009). New insights into rhythmic brain activity from TMS–EEG studies. *Trends in cognitive sciences*, *13*(4), 182-189.
- Thut, G., Miniussi, C., & Gross, J. (2012). The Functional Importance of Rhythmic Activity in the Brain. *Current Biology*, *22*(16), R658-R663.
doi:<https://doi.org/10.1016/j.cub.2012.06.061>
- Thut, G., Nietzel, A., Brandt, S. A., & Pascual-Leone, A. (2006). α -Band Electroencephalographic Activity over Occipital Cortex Indexes Visuospatial Attention Bias and Predicts Visual Target Detection. *The Journal of Neuroscience*, *26*(37), 9494. doi:[10.1523/JNEUROSCI.0875-06.2006](https://doi.org/10.1523/JNEUROSCI.0875-06.2006)
- Vassileiou, B., Meyer, L., Beese, C., & Friederici, A. D. (2018). Alignment of alpha-band desynchronization with syntactic structure predicts successful sentence comprehension. *NeuroImage*, *175*, 286-296.
doi:<https://doi.org/10.1016/j.neuroimage.2018.04.008>
- Vertes, R. P. (2005). Hippocampal theta rhythm: A tag for short-term memory. *Hippocampus*, *15*(7), 923-935. doi:[10.1002/hipo.20118](https://doi.org/10.1002/hipo.20118)
- Vigário, R. N. (1997). Extraction of ocular artefacts from EEG using independent component analysis. *Electroencephalography and Clinical Neurophysiology*, *103*(3), 395-404.
doi:[10.1016/S0013-4694\(97\)00042-8](https://doi.org/10.1016/S0013-4694(97)00042-8)
- Walker, P. (2008). Font tuning: A review and new experimental evidence. *Visual Cognition*, *16*(8), 1022-1058.
- Wamain, Y., Tallet, J., Zanone, P.-G., & Longcamp, M. (2012). Brain responses to handwritten and printed letters differentially depend on the activation state of the

- primary motor cortex. *NeuroImage*, 63(3), 1766-1773.
doi:<https://doi.org/10.1016/j.neuroimage.2012.07.020>
- Warren, L. R., Peltz, L., & Haueter, E. S. (1976). Patterns of EEG alpha during word processing and relations to recall. *Brain and Language*, 3(2), 283-291.
doi:[https://doi.org/10.1016/0093-934X\(76\)90023-7](https://doi.org/10.1016/0093-934X(76)90023-7)
- Weiss, S., & Mueller, H. M. (2003). The contribution of EEG coherence to the investigation of language. *Brain and Language*, 85(2), 325-343. doi:[https://doi.org/10.1016/S0093-934X\(03\)00067-1](https://doi.org/10.1016/S0093-934X(03)00067-1)
- Weiss, S., & Rappelsberger, P. (2000). Long-range EEG synchronization during word encoding correlates with successful memory performance. *Cognitive Brain Research*, 9(3), 299-312. doi:[https://doi.org/10.1016/S0926-6410\(00\)00011-2](https://doi.org/10.1016/S0926-6410(00)00011-2)
- Werkle-Bergner, M., Müller, V., Li, S.-C., & Lindenberger, U. (2006). Cortical EEG correlates of successful memory encoding: Implications for lifespan comparisons. *Neuroscience & Biobehavioral Reviews*, 30(6), 839-854.
doi:<https://doi.org/10.1016/j.neubiorev.2006.06.009>
- White, T. P., Jansen, M., Doege, K., Mullinger, K. J., Park, S. B., Liddle, E. B., . . . Liddle, P. F. (2013). Theta power during encoding predicts subsequent-memory performance and default mode network deactivation. *Human Brain Mapping*, 34(11), 2929-2943.
doi:10.1002/hbm.22114
- Wianda, E., & Ross, B. (2019). The roles of alpha oscillation in working memory retention. *Brain Behav*, e01263. doi:10.1002/brb3.1263
- Wickens, D. D. (1973). Some characteristics of word encoding. *Memory & Cognition*, 1(4), 485-490. doi:10.3758/bf03208913
- Xia, Z., Zhang, L., Hoeft, F., Gu, B., Gong, G., & Shu, H. (2017). Neural correlates of oral word reading, silent reading comprehension, and cognitive subcomponents.

International Journal of Behavioral Development, 42(3), 342-356.

doi:10.1177/0165025417727872

Yue, C. L., Castel, A. D., & Bjork, R. A. (2013). When disfluency is-and is not-a desirable difficulty: The influence of typeface clarity on metacognitive judgments and memory. *Memory and Cognition*, 41(2), 229-241. doi:10.3758/s13421-012-0255-8

Zumer, J. M., Scheeringa, R., Schoffelen, J.-M., Norris, D. G., & Jensen, O. (2014). Occipital alpha activity during stimulus processing gates the information flow to object-selective cortex. *PLOS Biology*, 12(10), e1001965.

Appendix A: Alien Task

Species pair A

The Pang	The Gerish
Ten feet tall	Ten feet wide
Eats green vegetables	Eats green fruit
Has a bushy purple tail	Has a bushy purple mane
Has blue eyes	Has blue toes
Has smooth, soft skin	Has smooth, soft hands
Females lay their young on piles of soil at birth	Females lay their young on piles of soil at feeding
Males collect food for their young	Males collect food for their partners

Species pair B

The Derl	The Enga
Five feet tall	Five feet wide
Eats the bark of maples	Eats the bark of gums
Has a line of orange spikes down its back	Has a line of orange spikes down its forehead
Has black eyes	Has black toes
Has thick, tough skin	Has thick, tough scales
Females usually travel in groups	Females usually travel in pairs
Males tend to wander alone	Males tend to wander together

Appendix B: Tests of fixed effects

Source	F	sig.
Intercept	0.001	.974
Region	3.226	.043
Hemisphere	1.874	.173
Fluency	1.274	.261
Region*Hemisphere	0.425	.655
Region*Fluency	0.087	.917
Hemisphere*Fluency	0.074	.785
Region*Hemisphere*Fluency	0.096	.909